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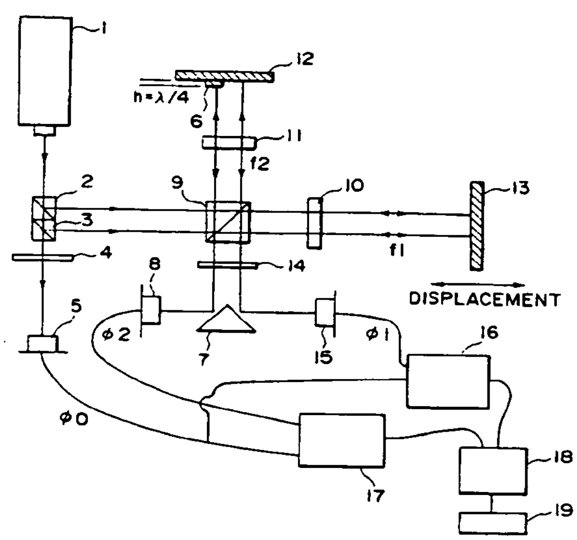
(54) Displacement measuring method and apparatus

(57) A displacement measuring method for measuring displacement of an object to be examined is disclosed, wherein light which contains two components having a small difference in frequency is separated into a first light of a firs wavelength and a second light of a second wavelength, having different frequencies. First light beam of the first light and a second light beam of the second light interfere with each other, wherein at least one of the first and second light beams is directed via the object, whereby a first light beat signal is produced. Third light beam of the first light and a fourth light beam of the second light interfere with each other, wherein at least one of the third and fourth light beams is directed via the object, whereby a second light beat signal having a predetermined phase difference as compared with the first light beat signal is produced. Then, displacement of the object is measured on the basis of a phase resulting from comparison of the phases of the first and second light beat signals.



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under ordinary interference conditions a change of $(K_2-K_1)(L_S+L_1)$ can be disregarded, $\Delta\phi= 2K_1\Delta L$. Thus, it changes linearly with a change of ΔL. Therefore, it is possible to detect a displacement ΔL of the object very precisely, by detecting the phase difference $\Delta\phi$.

As another example of measuring apparatus based on optical heterodyne interference method, Figure 2 illustrates a positional deviation detecting system for a diffraction grating (Japanese Laid-Open Patent Application, Laid-Open No. 90006/1990, for example). In this system, laser light from a dual wavelength orthogonal polarization laser (Zeeman laser) 140 is bisected into lights of two wavelengths by means of a polarization beam splitter 142, and the lights are projected to one or more diffraction gratings (here, 171 - 173 in Figure 3). From diffraction lights produced by the diffraction gratings, light beat signals are produced. By detecting and comparing phases of the beat signals, the position of that diffraction grating or any relative positional deviation between those diffraction gratings is detected very precisely. Thus, such system is used in alignment systems of many semiconductor exposure apparatuses.

Due to incompleteness of orthogonality of polarization of laser light or incompleteness of optical parts, however, generally polarization is disturbed. Thus, polarized lights and frequencies do not correspond to each other completely. As a result, the measur d phase and the optical path difference to be measured are not in a simple linear relationship, and this leads to an error in the interference measurement.

This will be explained in more detail by reference to Figure 1. The lights 315 (E_{2S}) and 316 (E_{1S}) transmitted through or reflected by the polarization beam splitter 308 are, in an exact sense, as follows:

$$E_{1S} = A\exp[i\{w_1t + \phi_1 - K_1(L_S + L_1 + 2\Delta L)\}] + \alpha\exp[i\{w_2t + \phi 2 - K_2(L_S + L_1 + 2\Delta L)\}] \quad (9)$$

$$E_{2S} = B\exp[i\{w_2t + \phi_2 - K_2(L_S + L_1)\}] + \beta\exp[i\{w_1t + \phi_1 - K_1(L_S + L_1)\}] \quad (10)$$

wherein α and β are values each corresponding to crosstalk, and it is represented that light of component w_2 leaks by α/A into the path of light w_1 (light of component w_1 leaks by β/B into the path of light w_2). If γ is amplitude, the signal IAC to be detected practically by a phase meter, for example, is expressed as follows:

$$IAC = \gamma\cos\{(w_1 - w_2)t + (\phi_1 - \phi_2) + \Delta\phi\} \quad (11)$$

$$\tan\Delta\phi = \sin(2K_2\Delta L)/\{\cos(2K_2\Delta L) + (\alpha/B + \beta/A)\} \quad (12)$$

Namely, to a change of ΔL, the measured phase $\Delta\phi$ changes at a period of π/K_2.

Figure 4 illustrates results of calculation for measured values, produced from a phase change to displacement an object to be measured, in an example of leakage 0.1% (intensity ratio). Broken line corresponds to a case without leakage. The difference (measurement error) is large, of an order of several ten nanometers.

If a He-Ne laser is used to provide an interferometer system, in order to reduce the error not larger than 1 nm, the quenching ratio of the polarization beam splitter has to be not greater than 0.01%. It is difficult to produce a polarization beam splitter that satisfies such quenching ratio.

On the other hand, in a case where plural diffraction gratings are used for the positional deviation detection, as shown in Figure 2, due to the effect of leakage of light at a polarization beam splitter, the phase changes non-linearly to a displacement of a diffraction grating. This results in degradation of measurement reproducibility.

In an attempt to reducing such non-linear error, balanced detection method has been proposed in Japanese Laid-Open Patent Application, Laid-Open No. 259407/1990 or in "Applied Physics", Vol.58, No.10 (1989), pp89.

According to this method, in place of the polarizer 314, a polarization separating element 320 being tilted by $\pi/4$ radian about the axis of input light, such as illustrated in Figure 5, is used to produce a sum component and a differential component of two signals, which are then applied to detectors 321 and 322, respectively. Then, an output of a differential amplifiers 323 is applied to a phase difference meter 319. In this manner, the non-linear component is reduced. Practically, however, due to incompleteness of a light source and optical parts related to polarization, it is not easy to fix the polarization plane and to provide complete alignment of the polarization separating element 320 about the optical axis. Further, there is leakage of light produced by the polarization separating element 320 itself. Thus, it is not possible to completely remove the non-linear error.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a high-precision displacement measuring method and apparatus by which at least one of the problems described above and peculiar to an optical heterodyne interference measurement system is solved.

In accordance with an aspect of the present invention, there is provided a displacement measuring method for measuring displacement of an object to be examined, said method comprising the steps of: separating light which contains two components having a small difference in frequency into a first light of a firs wavelength and a second light of a second wavelength, having different frequencies; causing interference between a first light beam of the first light and a second light beam of the second light while directing at least one of the first and second light beams via the object, whereby a first light beat signal is produced; causing interference between a third light beam of the first light and a fourth light beam of the second light

tem in a semiconductor exposure apparatus, according to a third embodiment of the present invention.

Figure 10 is a schematic view for partially illustrating a mask, a wafer and alignment marks to be used in the third embodiment of Figure 9.

Figure 11 is a schematic view for explaining how to separate diffraction light, in the third embodiment of Figure 9.

Figure s 12A and 12B are graphs for explaining inconveniences involved in a conventional structure and how they are solved in the third embodiment.

Figure 13 is a schematic view of a registration precision measuring system according to a fourth embodiment of the present invention.

Figure 14 is a schematic view of an example of evaluation pattern used in the fourth embodiment of Figure 13.

Figure 15 is a schematic view, illustrating another example of pattern array.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 6 shows a first embodiment of the present invention, which is applied to a minute displacement measuring system. Zeeman laser 1 produces lights of orthogonal polarization states (P-polarized light of a frequency f_1 and S-polarized light of a frequency f_2) which are bisected by a beam splitter 2 with their polarization components without being changed thereby. The light is further bisected by another beam splitter 3.

Light passing both of the two beam splitters 2 and 3 is received by a polarizer 4 by which the polarization dir ctions of the components are registered. Thus, int rf rence occurs. The interference light is transformed by a sensor 5 into an electric signal, whereby a r ference beat signal is produced.

Light reflected by the beam splitter 2 impinges on a polarization beam splitter 9. Depending of the state of polarization, it is bisected into light of a frequency f_1 passing the beam splitter and light of a frequency f_2 reflected by the beam splitter. The light of frequency f_1 passed the polarization beam splitter 9 is reflected by a mirror 13 (object to be examined), and is projected on the polarization beam splitter 9. Here, the light passes twice through a quarter wave plate 10 disposed on the light path, such that, with rotation of the direction of polarization by 90 deg., the light is transformed into S-polarized light. Therefore, the light project d on the polarization beam splitter 9 is reflected thereby.

On the other hand, light of frequency f_2 reflected by the polarization beam splitter 9 is reflected by a fixed mirror 12 back again to the polarization beam splitter 9. Similarly, here, the light passes twice through a quarter wave plate 11 disposed on the light path. Thus, with rotation of the direction of polarization by 90 deg., the light is transformed into P-polarized light which now passes through the polarization beam splitter 9.

In the manner described above, lights of frequencies f_1 and f_2 advance along the same path. Polarizer 14 then registers the polarization directions, and interference occurs. The interference light is received by a sensor 15, whereby a first measurement beat signal is produced.

Light reflected by the polarization beam splitter 3 impinges on the polarization beam splitter 9. Depending on the state of polarization, it is bisected into light of a frequency f_1 passing the beam splitter and light of a frequency f_2 reflected by the beam splitter. The light of frequency f_1 passed the polarization beam splitter 9 is reflected by the mirror 13 (object to be examined), and is projected on the polarization beam splitter 9. Here, the light passes twice through a quarter wave plate 10 disposed on the light path, such that, with rotation of the direction of polarization by 90 deg., the light is transformed into S-polarized light. Therefore, the light projected on the polarization beam splitter 9 is reflected thereby.

On the other hand, light of frequency f_2 reflected by the polarization beam splitter 9 is reflected by a step portion 6 of the fixed mirror 12 back again to the polarization beam splitter 9. Similarly, here, the light passes twice through the quarter wave plate 11 disposed on the light path. Thus, with rotation of the direction of polarization by 90 deg., the light is transformed into P-polarized light which now passes through the polarization beam splitter 9.

In the manner described above, lights of frequencies f_1 and f_2 advance along the same path. The polarizer 14 then registers the polarization directions, and interference occurs. The interference light is received by the sensor 15, whereby a second measurement beat signal is produced.

Here, if the step 6 changes, the phases of the first and second measurement beat signals change. For example, if the height h of the step is set to satisfy $h = \lambda/4$ where λ is the wavelength of light used, a phase difference of π radian is produced between the two beat signals. In a case where a He-Ne laser is used, the step is of about 158 nm, and it may be formed easily and accurately by a known method such as vapor deposition, for example. Separation of two measurement beat signals may be done by using a prism mirror 7, for example.

An example of signal processing method will be explained below. Detecting the phase difference ($\phi_1 - \phi_0$) between a measurement beat signal 1 and a reference beat signal through a phase difference meter 16, it changes with displacement of the mirror 13 in the manner such as illustrated in Figure 7A. Also, det cting the phase difference ($\phi_2 - \phi_1$) between a measurement signal 2 and the reference beat signal through a phase difference meter 17, a signal having

37, is equipped with a transmitting area. The other area to be irradiated with alignment light has such a mask structure effective to block the alignment light to thereby prevent production of unwanted light. In Figure 10, the mark on the mask denoted at 38 is a mark which is going to be printed on the wafer so that the printed mark will be used in the subsequent exposure process. A region denoted at 32 corresponds to a scribe line, and a region denoted at 33 corresponds to a circuit pattern area, a region denoted at 34 corresponds to the range to be irradiated with the exposure light.

Diffraction lights from the alignment marks 36 and 37 go along substantially the same path, and they are reflected by a mirror 21. Then the lights pass through a lens 39 and a polarizer 30, and the marks 36 and 37 are imaged at the position of an edge mirror 41 such as illustrated in Figure 11. Here, the diffraction light from the alignment mark 36 passes the edge mirror and, as shown in Figure 6, again it is re-imaged at the edge mirror 44 position. Thus, the diffraction light is divided into diffraction light from the diffraction grating 36a and diffraction light from the diffraction grating 37b. The divided diffraction light goes through a collecting lens 49 or 48, and it is photoelectrically detected by a sensor 58 or 57. On the other hand, the diffraction light from the alignment mark 37 as reflected by the edge mirror 41 is similarly divided into diffraction light from the diffraction grating 37b and diffraction light from the diffraction grating 37a. Thereafter, they are detected by sensors 56 and 57, r spectively.

With respect to the lens 39, the wafer 52 (mask 36) and the edge mirror 41 are placed in an optically conjugate relationship. Additionally, the edge mirror 41 is optically conjugate with the sensors 55 - 58. Namely, the wafer (mask) is in an optically conjugate r lationship with the sensors. Thus, the system is stiff against tilt of the wafer and the mask.

Beat signal IMa being photoelectrically detected by the sensor 55, if α and β are amplitudes of leakage lights to the amplitudes A and B of regular reflection light and regular transmission light of the polarization beam splitter 9 and if AM is the amplitude, is such as follows:

$$IMa = AM\cos\{(w_1 - w_2)t + \Delta\phi M\} \quad (15)$$

$$\tan(\Delta\phi M) = \sin(4\pi\Delta XM/P)/\{\cos(4\pi\Delta XM/P) + (\alpha/B + \beta/A)\} \quad (16)$$

wherein ΔXM is the amount of deviation of the alignment mark 36a from a reference line, and P is the pitch of the alignment mark 36.

Also, the beat signal IMb being photoelectrically detected by the sensor 58 is such as follows:

$$IMb = AM\cos\{(w_1 - w_2)t + \Delta\phi M') \quad (17)$$

$$\tan(\Delta\phi M') = \sin(4\pi\Delta XM/P + \pi)/\{\cos(4\pi\Delta XM/P + \pi) + (\alpha/B + \beta/A)\} \quad (18)$$

On the other hand, the beat signal IWa being photoelectrically detected by the sensor 57, if α and β are amplitudes of leakage light to the amplitudes A and B of regular reflection light and regular transmission light of the polarization beam splitter 9 and if AW is the amplitude, is such as follows:

$$IWa = AW\cos\{(w_1 - w_2)t + \Delta\phi W\} \quad (19)$$

$$\tan(\Delta\phi W) = \sin(4\pi\Delta XW/P)/\{\cos(4\pi\Delta XW/P) + (\alpha/B + \beta/A)\} \quad (20)$$

wherein ΔXW is the amount of deviation of the alignment mark 37a from a reference line, and P is the pitch of the alignment mark 37.

Also, the beat signal IWb being photoelectrically detected by the sensor 56 is such as follows:

$$IWb = AW\cos\{(w_1 - w_2)t + \Delta\phi w') \quad (21)$$

$$\tan(\Delta\phi W') = \sin(4\pi\Delta XW/P + \pi)/\{\cos(4\pi\Delta XW/P + \pi) + (\alpha/B + \beta/A)\} \quad (22)$$

Here, the difference of the beat signals represented by equations (15) and (19), that is, $\Delta\phi M - \Delta\phi W$, is detected by a dual-channel phase difference meter 59. Even when the relative positional deviation between the alignment marks 36 and 37 is constant, as illustrated in Figure 12A, this phase difference signal changes along a sine curve at a period P/2 with a positional deviation between the reference line of the alignment optical system and the alignment marks 36 and 37, in the alignment direction (in other words, a deviation between the beam spot and the alignment mark). In exposure apparatuses, alignment marks should be renewed sequentially and the alignment optical system has to be moved sequentially with the renewal. Conventionally, there has been no suitable device for positioning the beam spot and the alignment mark with such precision (e.g. not greater than P/5). As a result, an alignment error corresponding to the amplitude shown in Figure 12A occurs. Other factors for causing such error may be a positioning error, for example, in respect to the mask chucking position.

Taking the phase difference $\Delta\phi M' - \Delta\phi W'$ between the beat signals expressed by equations (17) and (21) through the phase difference meter 59, a signal with a characteristic having a non-linear error shifted by 1/2 period, such as shown in Figure 12B, is provided. Thus, by detecting an average ϕ of these two phase difference signals by use of the operational device 18, it is possible to cancel the non-linear error. Here, the relative positional deviation ΔX of the mask and the wafer can be determined by $\Delta X = \phi \cdot P(4\pi)$.

After detection of the positional deviation, a drive signal corresponding to the deviation is applied from an unshown driver to an actuator 60M, for driving the mask 35, and/or to an actuator 60W, for driving the wafer stage 61, to move one of or both of the mask and the wafer so that the positional error comes into a tolerable range.

While the foregoing description has been made with respect to one axis (X direction), it is also with the case of the Y direction. That is, additional sets of alignment marks (not shown) are provided on the

$$\sin(4\pi\Delta X_2/P + \pi)/\{\cos(4\pi\Delta X_2/P + \pi) + (\alpha/B + \beta/A)\} \quad (30)$$

Here, the difference of the beat signals represented by equations (23) and (27), that is, $\Delta\phi_1 - \Delta\phi_2$, is detected by a dual-channel phase difference meter 59. Even when the relative positional deviation between the evaluation patterns 70 and 71 is constant (namely, the same registration error), as illustrated in Figure 12A, this phase difference signal changes along a sine curve at a period P/2 with a positional deviation between the reference line of the optical system and the evaluation patterns 70 and 71 (in other words, a deviation between the beam spot and the evaluation pattern). In registration measuring systems, it is necessary to perform measurement of registration error at various sites in a shot of a wafer. Also, it is necessary to perform measurement with respect to various shots on a wafer. Thus, the wafer has to be moved to place each evaluation pattern at the measurement position. Conventionally, there has been no suitable device for positioning the beam spot and the evaluation pattern with such precision (e.g. not greater than P/5). As a result, an error of measurement reproducibility corresponding to the amplitude shown in Figure 12A occurs.

Taking the phase difference $\Delta\phi_1' - \Delta\phi_2'$ between the beat signals expressed by equations (25) and (29) through the phase difference meter 59, a signal with a characteristic having a non-linear error shifted by 1/2 period, such as shown in Figure 12B, is provided. Thus, by detecting an average ϕ of these two phase diff rence signals by use of the operational device 18, it is possible to cancel the non-linear error. Here, the relative positional deviation ΔX of the mask and th wafer can be determined by:

$$\Delta X = \phi \cdot P(4\pi) \quad (31)$$

Other than the pattern arrangements of the third and fourth embodiments, an arrangement shown in Figure 15 may be used, wherein diffraction gratings 90a and 90b and diffraction gratings 91a and 91b of marks 90 and 91 have a mutual shift X_0 in the X direction. However, there is a necessity of shifting the non-linear error by 1/2 period, if the pitch of the diffraction grating is P and n is an integer, the amount of shift may be selected in the range of $X_0 = (2n+1) \cdot P/4$.

While in the foregoing description the invention has been described with reference to examples where a Zeeman laser is used as a light source, as a matter of course a mono-frequency laser may be used: laser light from such laser may divided by a polarization beam splitter and, thereafter, an acousto-optic element may be used to perform frequency modulation thereto, whereby two light beams of different frequencies and having orthogonal polarization states are provided.

While the invention has been described with reference to the structures disclosed herein, it is not confined to the details set forth and this application is intended to cover such modifications or changes as may come within the purposes of the improvements or the scope of the following claims.

Claims

1. A displacement measuring method for measuring displacement of an object to be examined, said method comprising the steps of:

   separating light which contains two components having a small difference in frequency into a first light of a firs wavelength and a second light of a second wavelength, having different frequencies;

   causing interference between a first light beam of the first light and a second light beam of the second light while directing at least one of the first and second light beams via the object, whereby a first light beat signal is produced;

   causing interference between a third light beam of the first light and a fourth light beam of the second light while directing at least one of the third and fourth light beams via the object, whereby a second light beat signal having a predetermined phase difference as compared with the first light beat signal is produced; and

   measuring displacement of the object on the basis of a phase resulting from comparison of the phases of the first and second light beat signals.

2. A method according to Claim 1, wherein the predetermined phase difference is π radian.

3. A method according to Claim 1, wherein said measuring step includes detecting a sum of the first phase and a phase provided by adjusting the phase of the second light beat signal by an amount corresponding to the predetermined phase difference.

4. A method according to Claim 1, further comprising applying a phase difference to the third light beam and the fourth light beam, prior to producing the second light beat signal with the third and fourth light beams.

5. A method according to Claim 1, wherein the first and second light beams are directed via a first diffraction grating provided on the object, and wherein the third and fourth light beams are directed via a second diffraction grating provided on the object and having the same pitch and the same array direction as of the first diffraction grating.

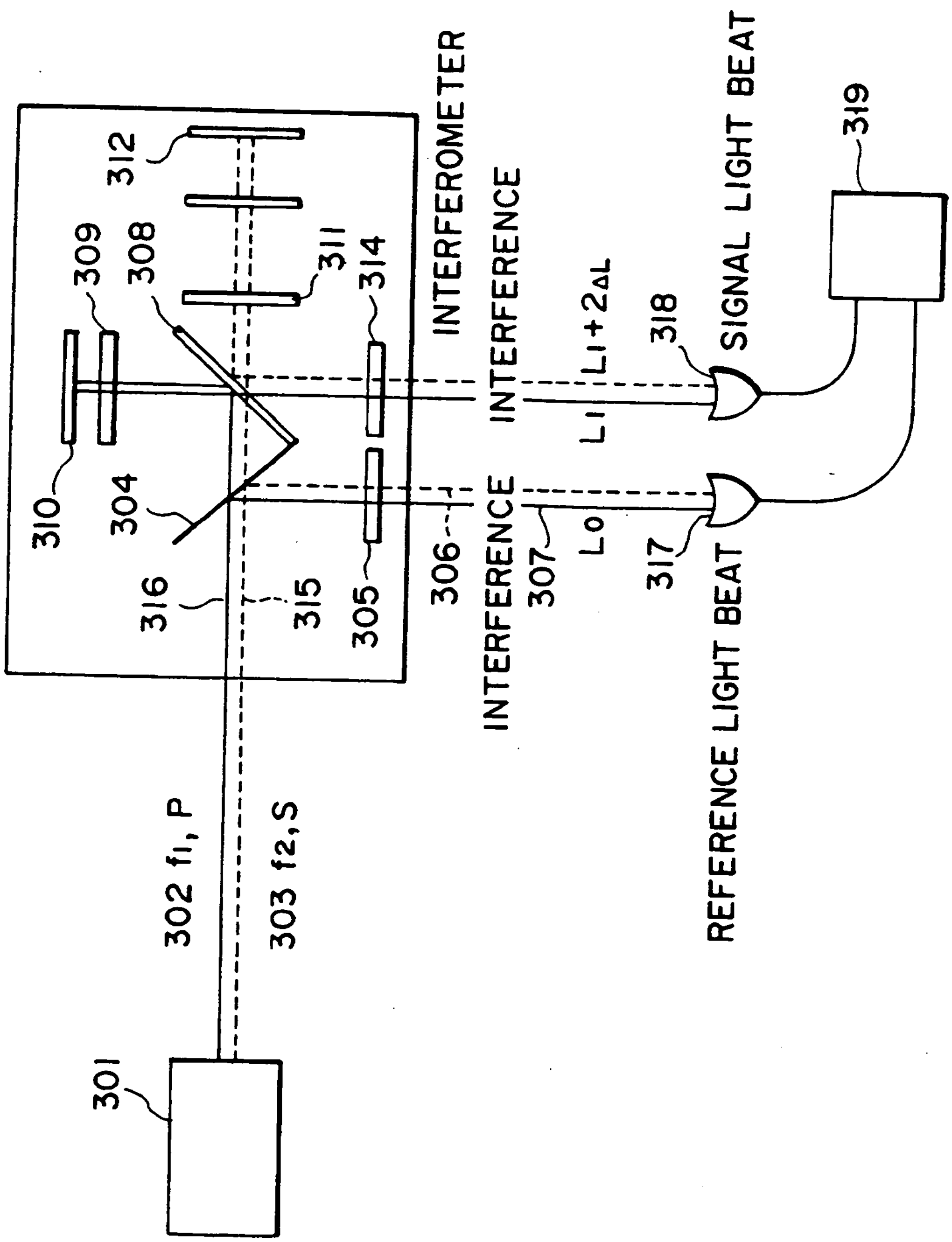

INTERFEROMETER
312
309
308
311
314
INTERFERENCE
INTERFERENCE
L1+2ΔL
L1
318
SIGNAL LIGHT BEAT
319
310
304
316
315
305
306
INTERFERENCE
307
L0
317
REFERENCE LIGHT BEAT
302 f1, P
303 f2, S
301

FIG. 1

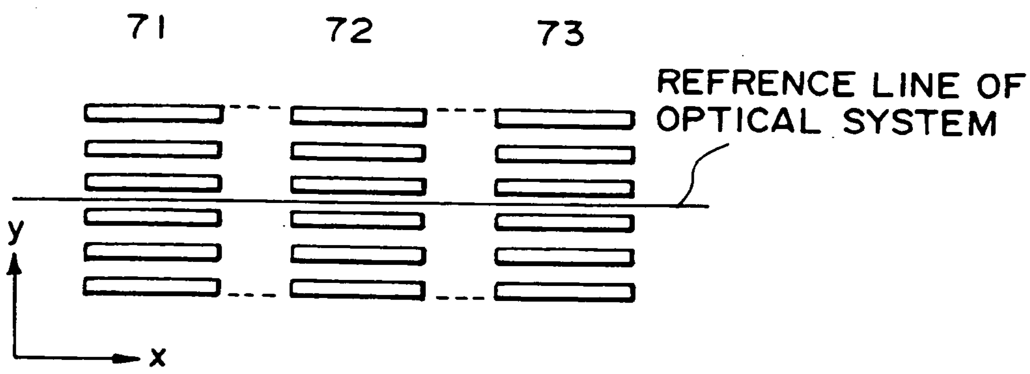

71
72
73
REFRENCE LINE OF
OPTICAL SYSTEM
y
x

FIG. 3

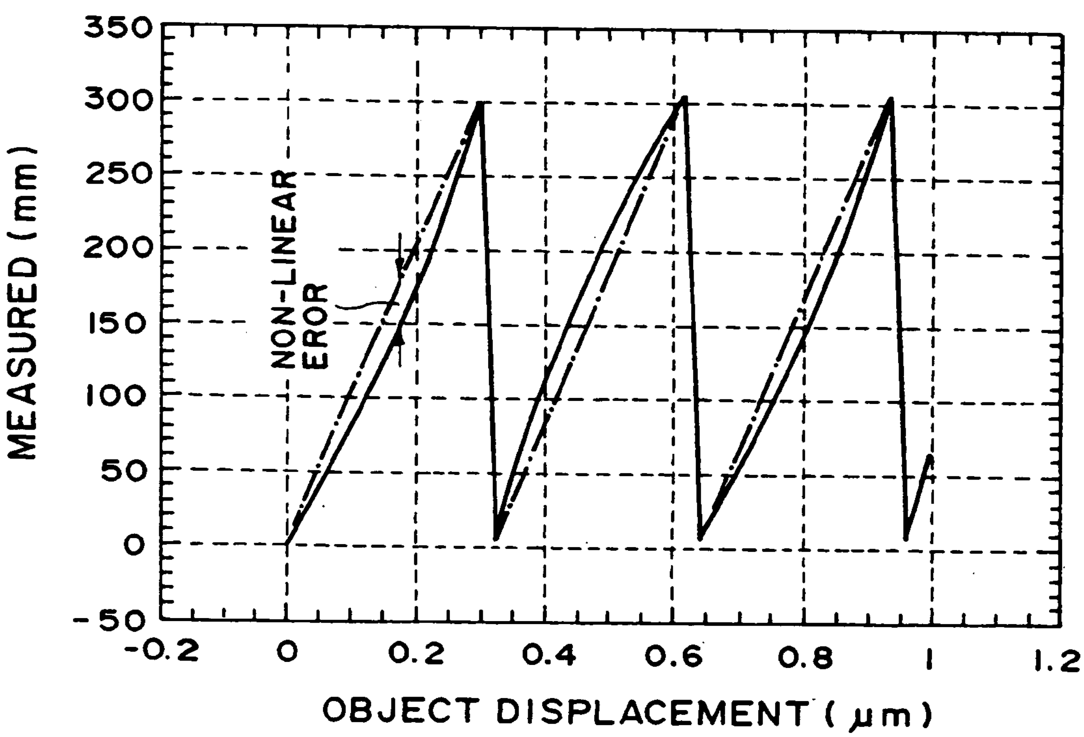

350
300
250
200
150
100
50
0
-50
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
MEASURED (mm)
OBJECT DISPLACEMENT (μm)
NON-LINEAR
EROR

FIG. 4

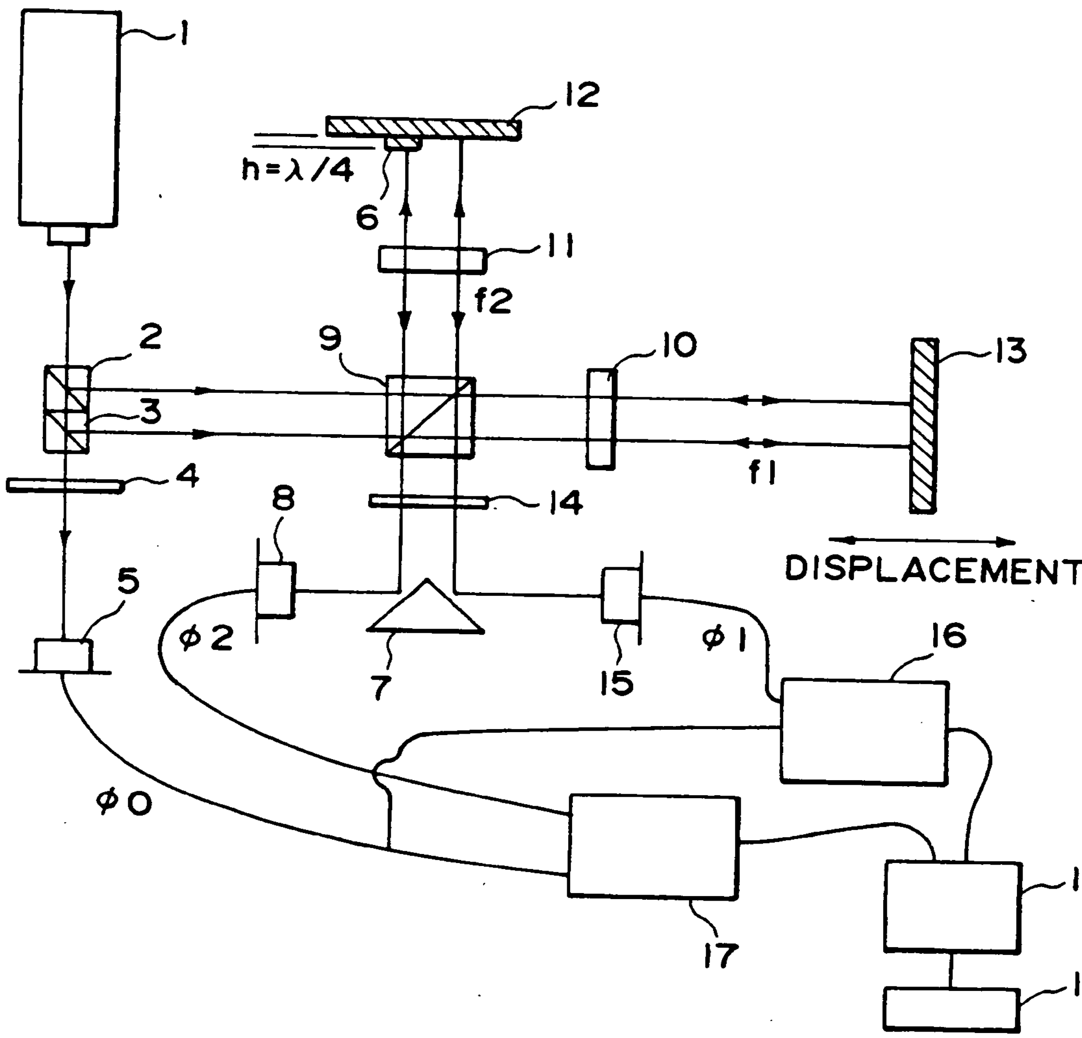
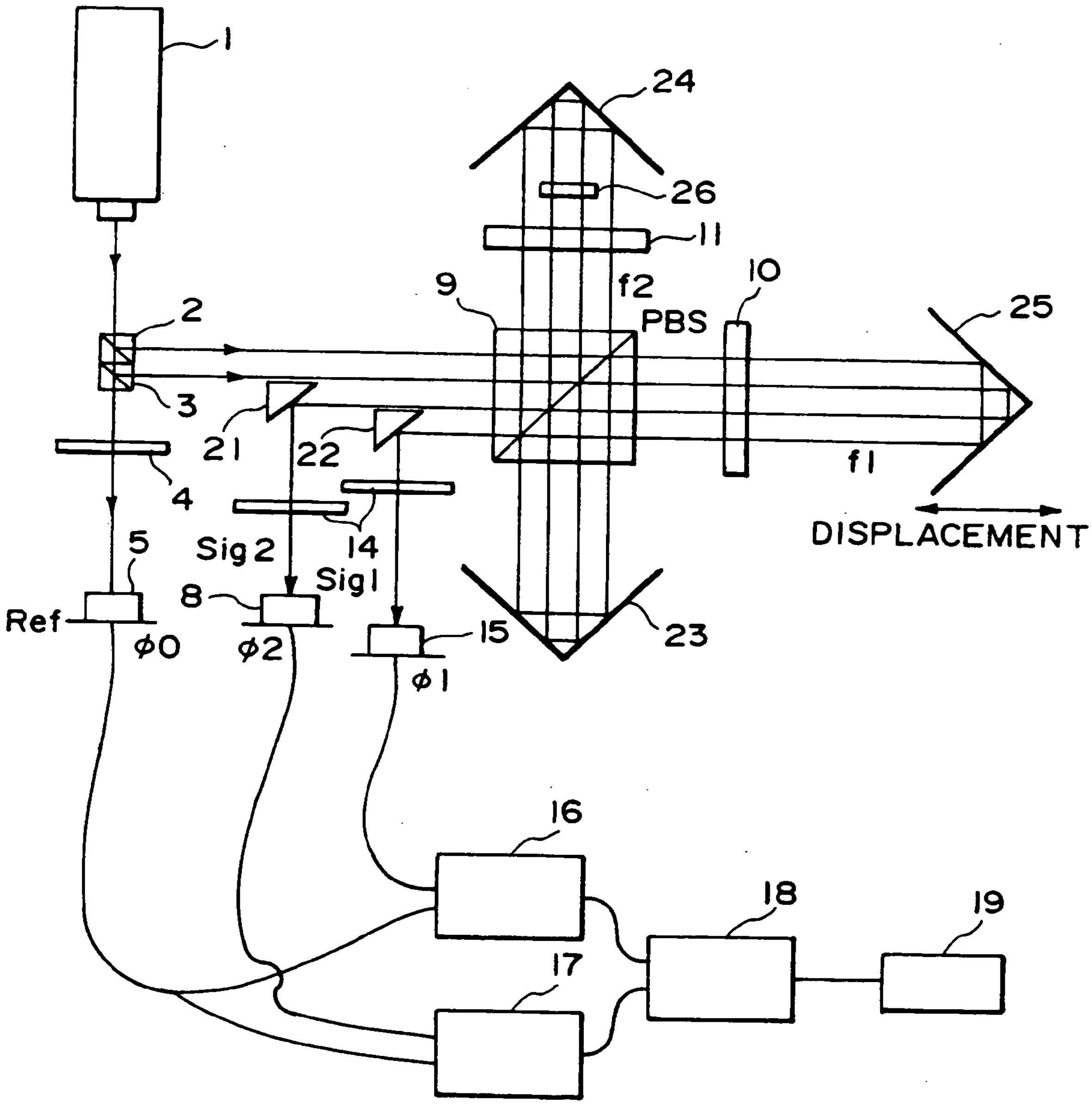

1
12
h=λ/4
6
11
f2
2
9
10
13
3
4
f1
8
14
DISPLACEMENT
5
φ2
7
15
φ1
16
φ0
18
17
19

FIG. 6


1
24
26
11
f2
9
10
PBS
2
25
3
21
22
f1
4
14
DISPLACEMENT
5
Sig 2
Sig1
8
Ref
ϕ0
ϕ2
15
23
ϕ1
16
18
19
17

F I G. 8

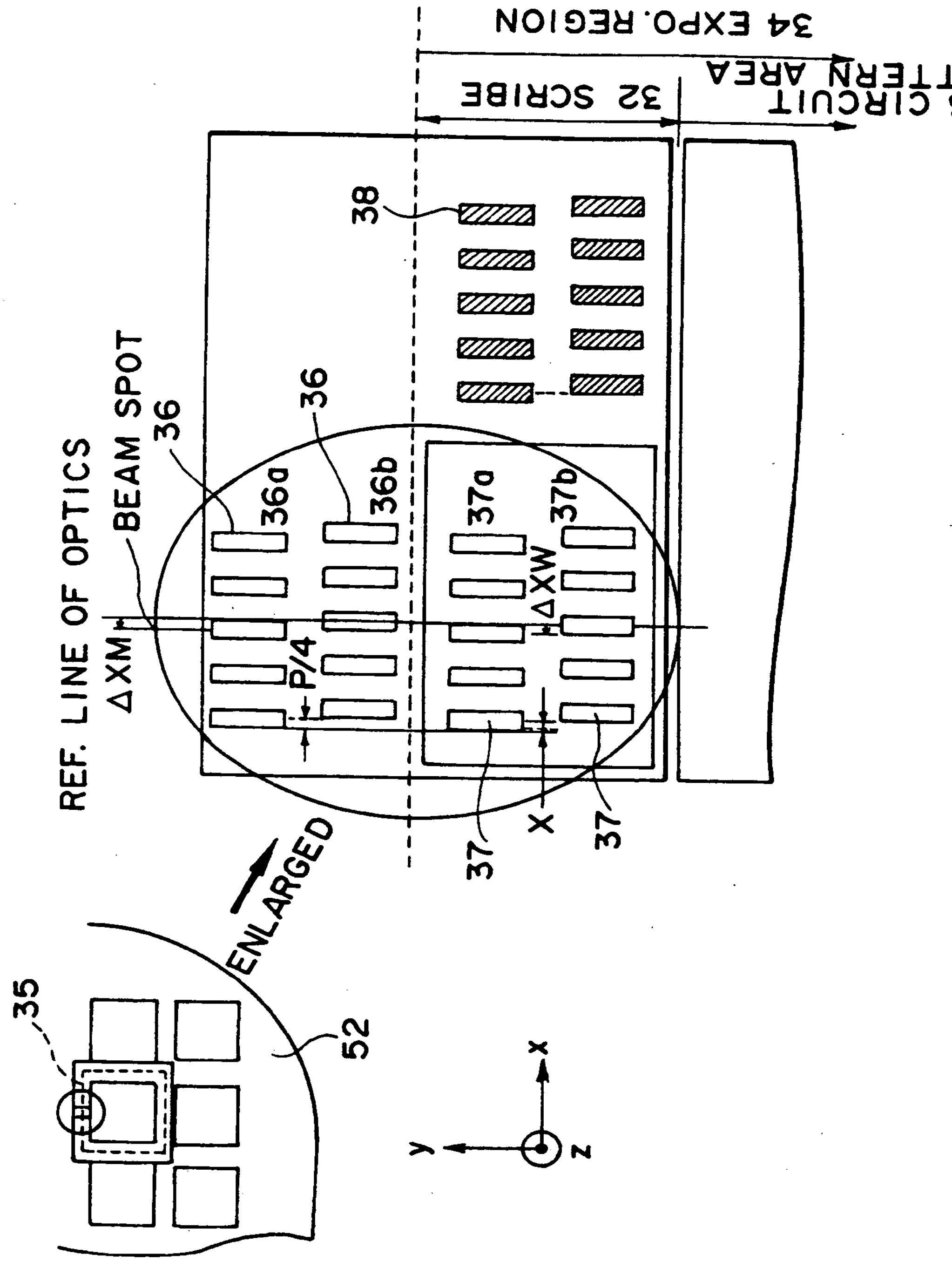


FIG. 10

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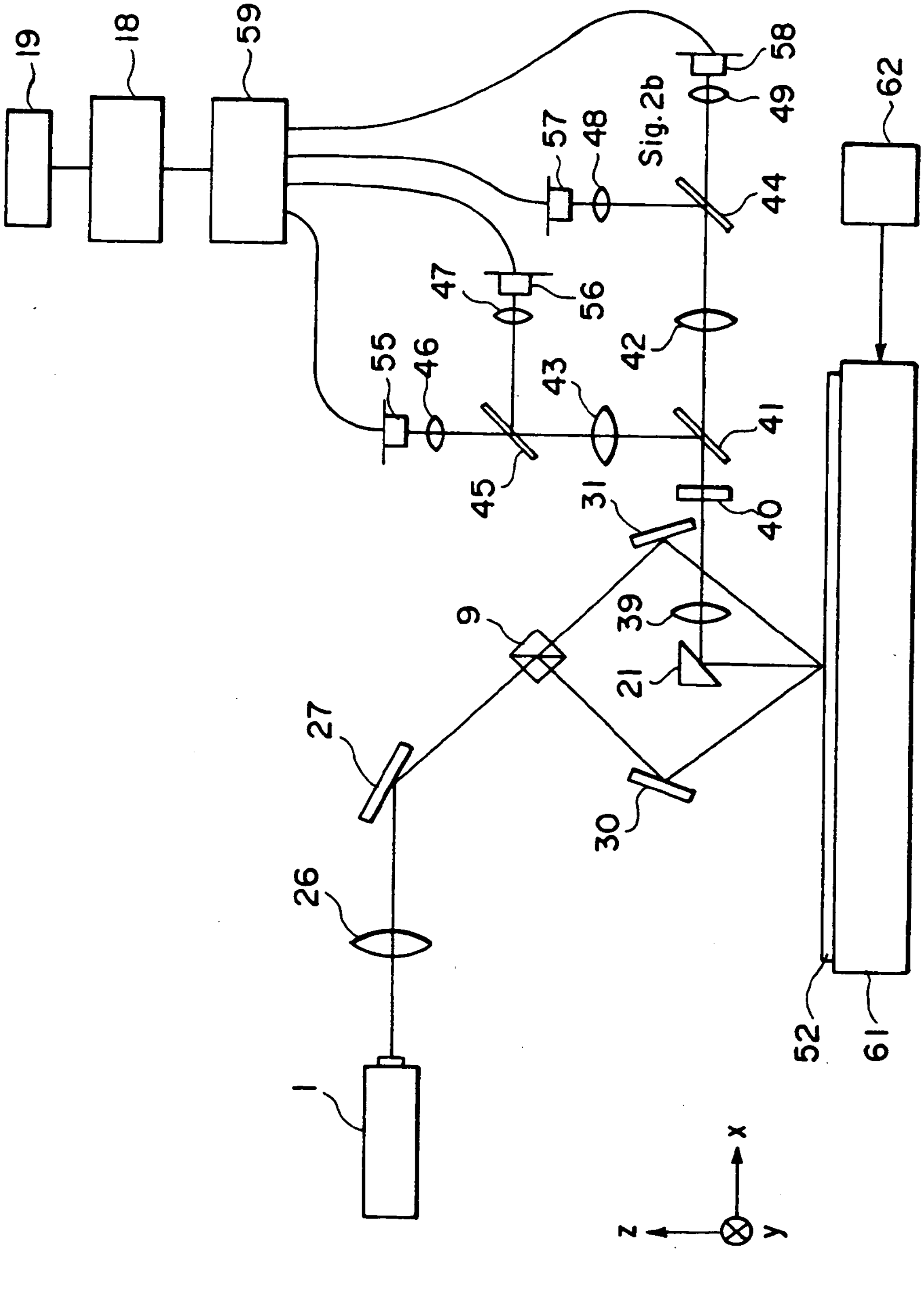
19
18
59
58
62
57
48
Sig.2b
49
44
47
56
42
55
46
43
41
45
31
40
9
39
27
21
30
26
52
61
1
x
z
y

FIG. 13

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(54) Displacement measuring method and apparatus

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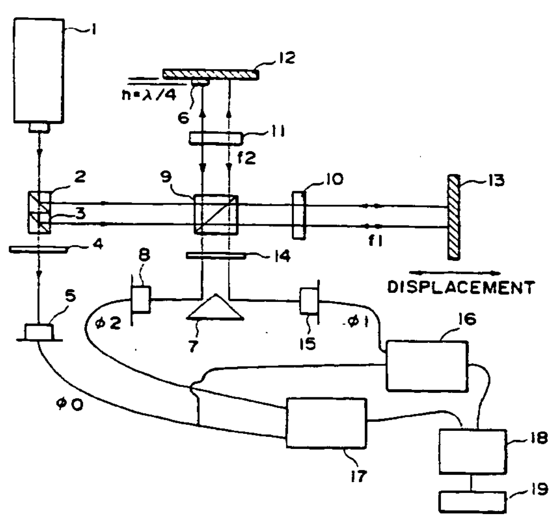

FIG. 6

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